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ANL CORE TOOLS - HARDWARE

PROJECT ID# EEMS041

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U.S. DEPARTMENT OF ENERGY
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OVERVIEW

Timeline

- Project Start Date – 10/1/2018
  - Task 1- Vehicle in the Loop (VIL)
  - Task 2- Aero
- Project End Date- 9/30/2021
- Percent Complete- 20%

Barriers Addressed:

- **Innovative Testing Methodologies**: Unique experimentation methods are required for analysis and model validation of the energy use impact of future mobility technologies

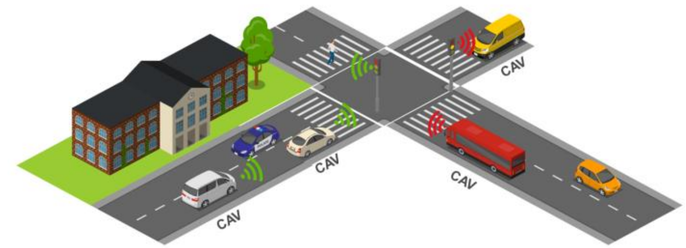
Budget

- FY19 Project Funding:
  - $500k: Vehicle in the Loop (VIL)
  - $250k: Aero
- FY20 Project Funding:
  - To Be Determined

Collaborations / Partners:

- Argonne / DOE Vehicle Modeling & Controls PI's
- DOE-Smart consortium researchers
- ANL Cybersecurity Research
- DOT- NHTSA

RELEVANCE



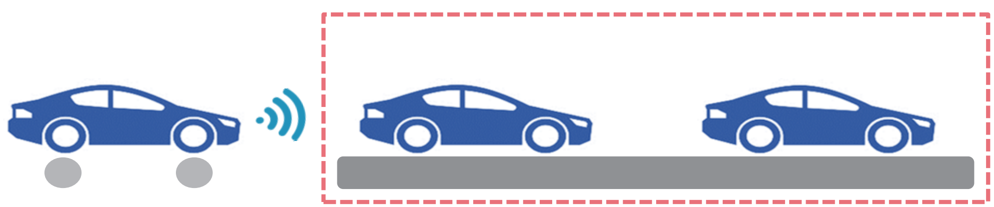
Impact

Unique experimentation and data-driven analysis to validate the energy impact of future mobility systems

Objectives

– Develop methodologies and facilities for precise, repeatable, flexible energy use evaluation of Connected and Automated Vehicles (CAVs)
  - Leverage laboratory grade research equipment to produce high-fidelity data for direct insight and model validation

– Evaluate the direct road load force requirement of varying following distances / speeds, allowing for recreation in laboratory environment



Dyno vehicle **Virtual Vehicles**

RELEVANCE- 20+ years of Contributions to Rapidly Evolving Automotive Technologies – Priority on data/analysis availability to stakeholders

Facilities and tools

- AVTC Testing @ EPA
- Clayton chassis rolls
- 4WD chassis dyno
- Modular Automotive Technology Testbed
- PEMS
- Hydrogen capable
- Modular DAQ
- Robot driver
- 2WD chassis dyno
- Thermal Chamber
- Downloadable Dynamometer Database
- Vehicle to grid
- Vehicle as sensor
- 4WD CAV Dyno Prototype
- Vehicle Override and Control
- Vehicle in the Loop

1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020

HEV Era **Plug-in Era** **CAVs Era**

Achievements

- 99 Japan Prius – component and control
- In-situ engine mapping
- Emulated battery in PHEV-FCV
- BMW Hydrogen 7
- All PHEV conversions
- OEM PHEVs
- X-prize
- Stranded Energy
- Thermal impact on HEV, BEV
- Thermal mule
- Thermal management
- ACC characterization
- Multi Vehicle Aero
- Longitudinal Control for Research
- SAE J1711 / J1634 / J2951 / J2608 / J2908 /….
- Continued Technology Assessment (CVs, HEVs, PHEVs, BEVs, Alt fuel)

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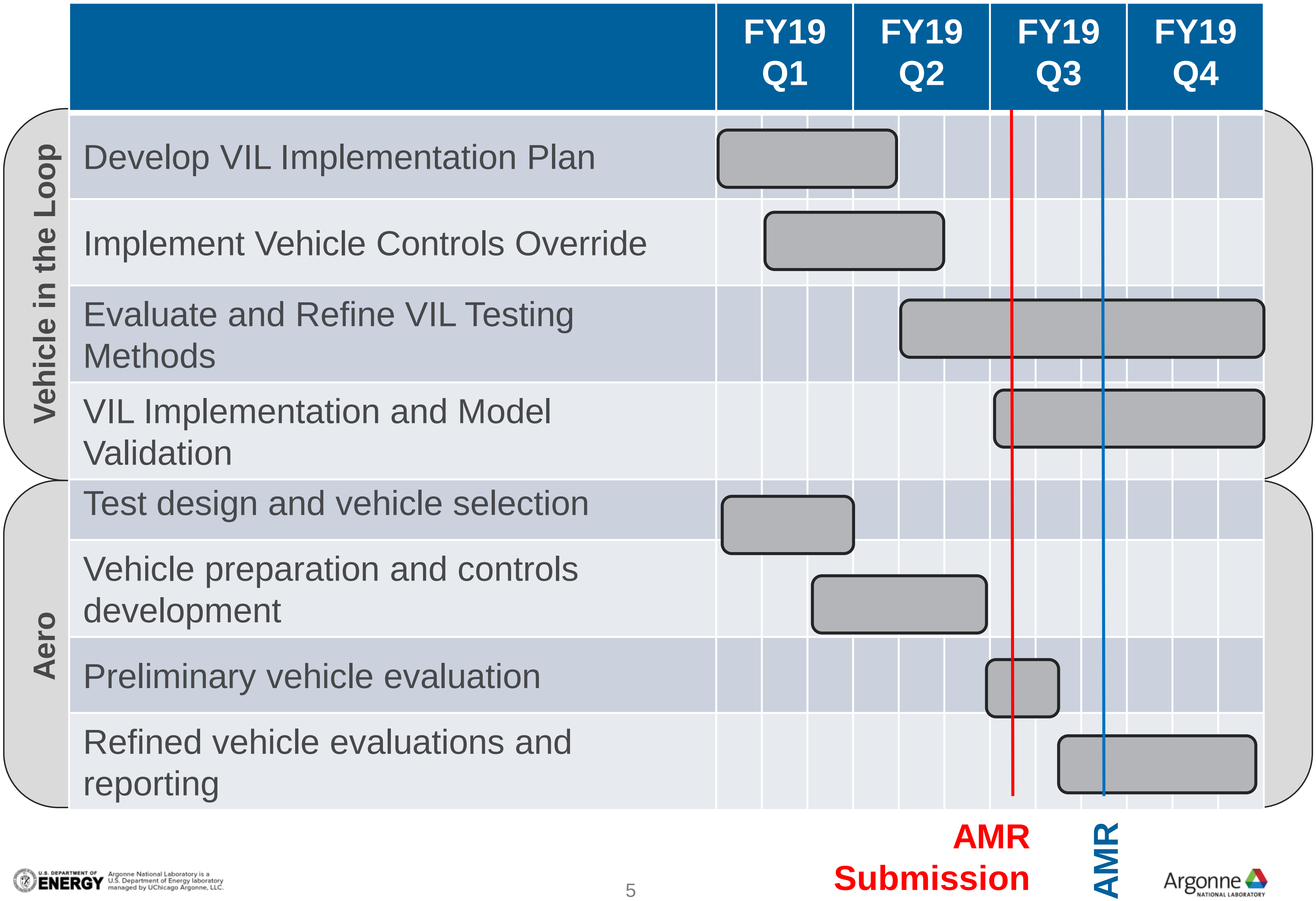
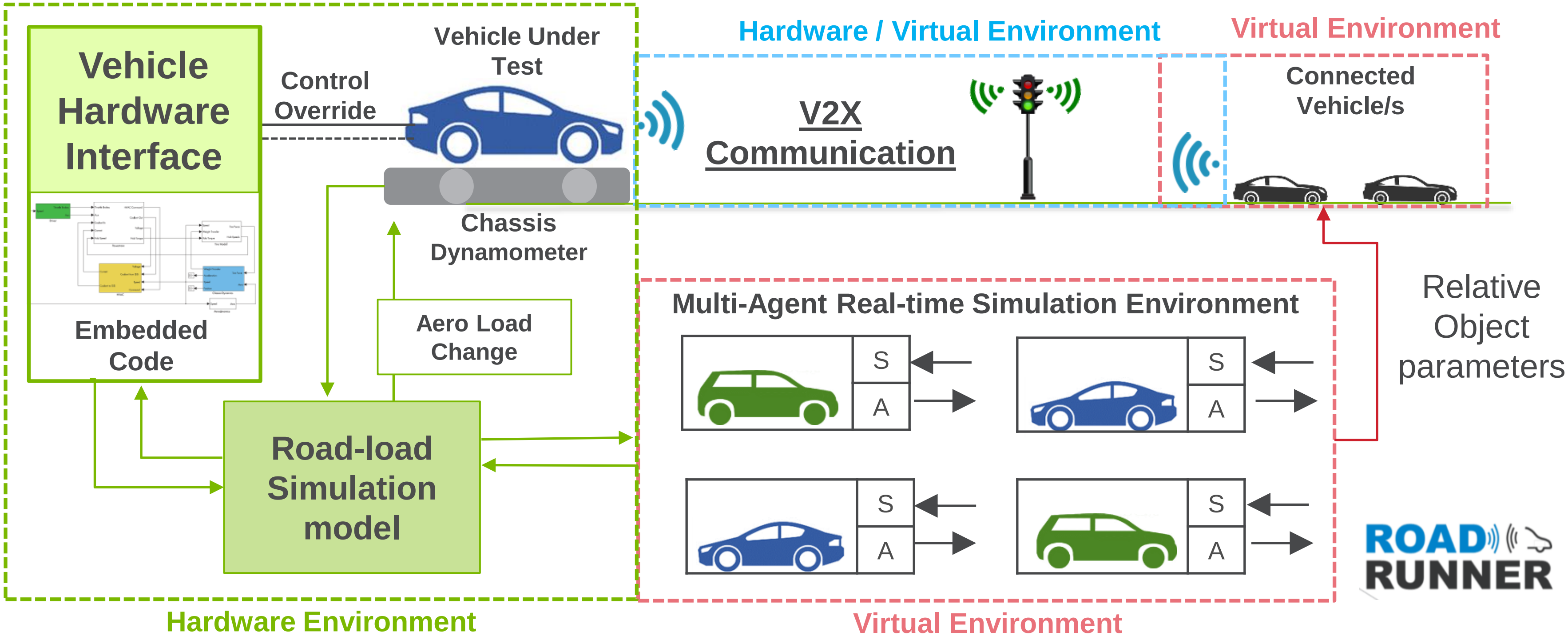
MILESTONES:



FY19 Q1
FY19 Q2
FY19 Q3
FY19 Q4
Vehicle in the Loop
Develop VIL Implementation Plan
Implement Vehicle Controls Override
Evaluate and Refine VIL Testing Methods
VIL Implementation and Model Validation
Aero
Test design and vehicle selection
Vehicle preparation and controls development
Preliminary vehicle evaluation
Refined vehicle evaluations and reporting
AMR Submission
AMR

APPROACH: VEHICLE IN THE LOOP (VIL) IMPLEMENTATION WITH DIRECT CONTROL OVERRIDE

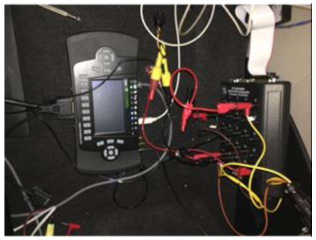


By providing a unique, vehicle system focused environment for intelligent/connected vehicle systems, Vehicle-in-the-Loop (VIL) offers the following benefits:

- Flexible- Variable vehicle (EV, Conv?) / Stationary instrumentation / Common software
- Precise and Repeatable- Controlled variation of specific test parameters
- Safe- Vehicle testing is in a stationary, controlled environment
- Reduced cost- Continuous testing (non human-driven) not requiring offsite travel
- Portable- Following validation, hardware and control may travel with vehicle (track testing?)

APPROACH: DIRECT AERO / ROADLOAD MEASUREMENTS ON-TRACK

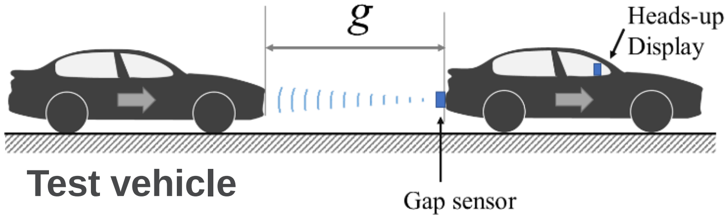
Instrumentation



Direct Road Load From Axle Torque

Track Testing Setup

Single Vehicle Evaluation



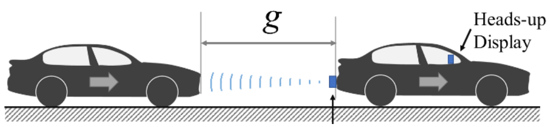
Multi Vehicle Evaluation

Test Methodology

- Directly measure tractive force
  - Axle shafts instrumented with torque sensors
- Steady-state force = road load
- Vehicle selection based upon vehicle profile
- Track based evaluation
  - Single vehicle requires practice
  - Multi vehicle requires automation
- Test consist of varying incremental gaps/speeds between vehicles of interest

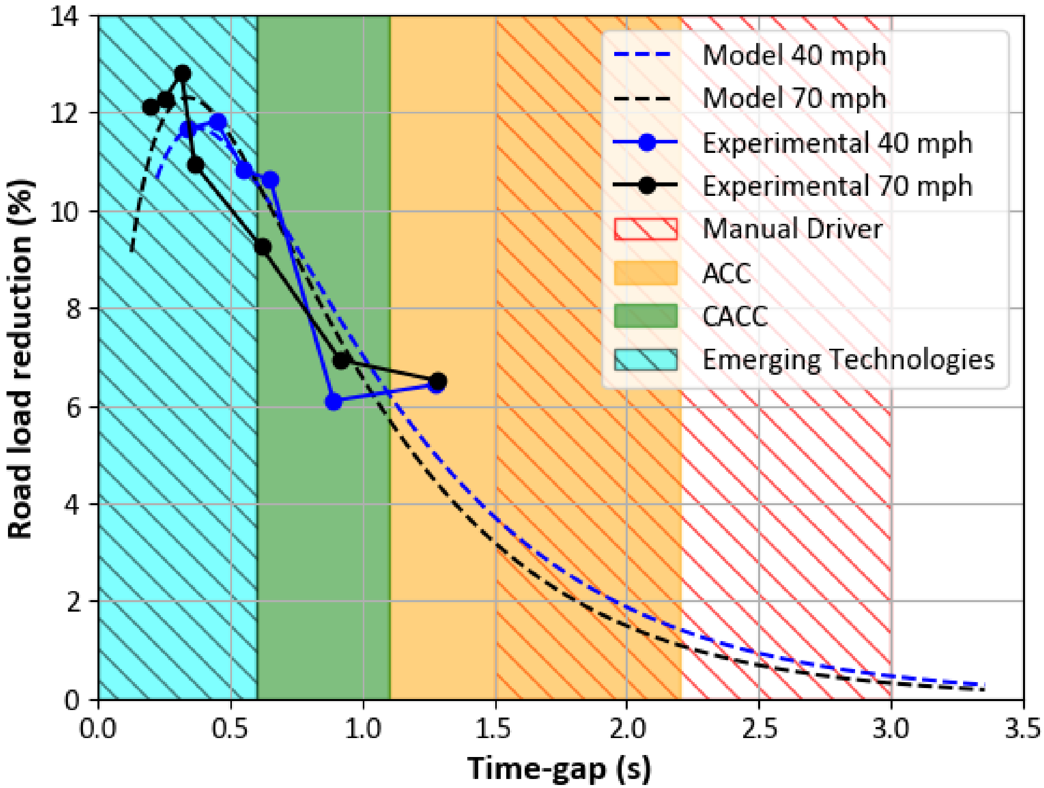
Track Overview

ACCOMPLISHMENTS: DIRECT AERO / ROADLOAD MEASUREMENTS ON-TRACK



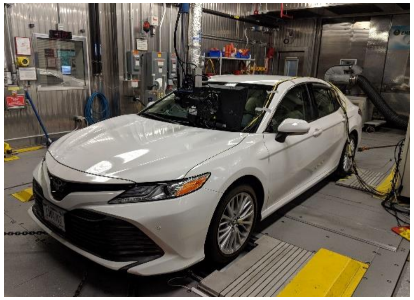
Testing Results

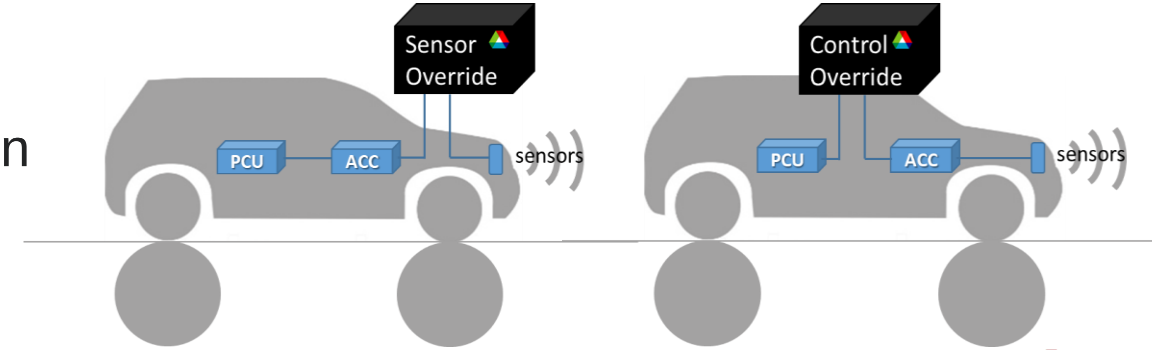
- Concept validated- additional testing required for robust results
- Data matches current models at higher speeds
- Results show additional longer distances needed to fully capture aero impact
- More opportunity for energy savings with gaps shorter than current CACC estimates



ACCOMPLISHMENTS: SUCCESSFUL VEHICLE-IN-THE-LOOP CONCEPT IMPLEMENTATION

- **Vehicle-centric research platform**
  - Enabled on multiple research vehicles
- Direct control overrides
  - Sensor Override
    - Vehicle control model remains
  - Acceleration Override
    - Research flexible control model
- Control capability is transferable:
  - Dyno / Track
- Safe, controlled, repeatable system operation and energy use assessment
- Leverage laboratory-grade facilities and instrumentation

2017 Toyota Prius Prime	**2018 Toyota Camry**
	
HEV/ PHEV / EV	Conventional



<u>ACCOMPLISHMENTS:</u> VIL IMPLEMENTATION- ENERGY USE OF LONGITUDINAL CONTROL MODELS

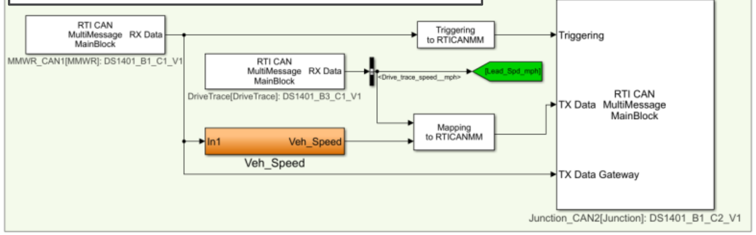
<u>Testing Objective</u>

- Develop and refine VIL testing methodology
  - Verification of testing environment
- Determine energy use impact of preliminary longitudinal control models on:
  - Standard drive cycles (UDDS, HWY, US06)
  - 3x cycle repeat
  - Hybrid vs EV operation

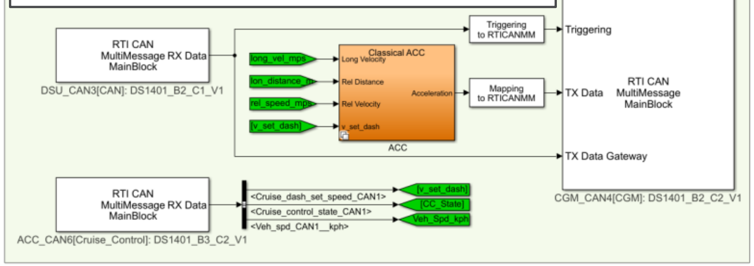
<u>Setup</u>

- Override Setup -
  - Multi-bus MIM override through common hardware
- Varying longitudinal control models vs baseline
  - <u>Baseline</u>- Trace follow w/ AMTL Robot driver
  - Stock ACC- Short Range (Object override)
  - Prototype control (Acceleration override)

Object Override



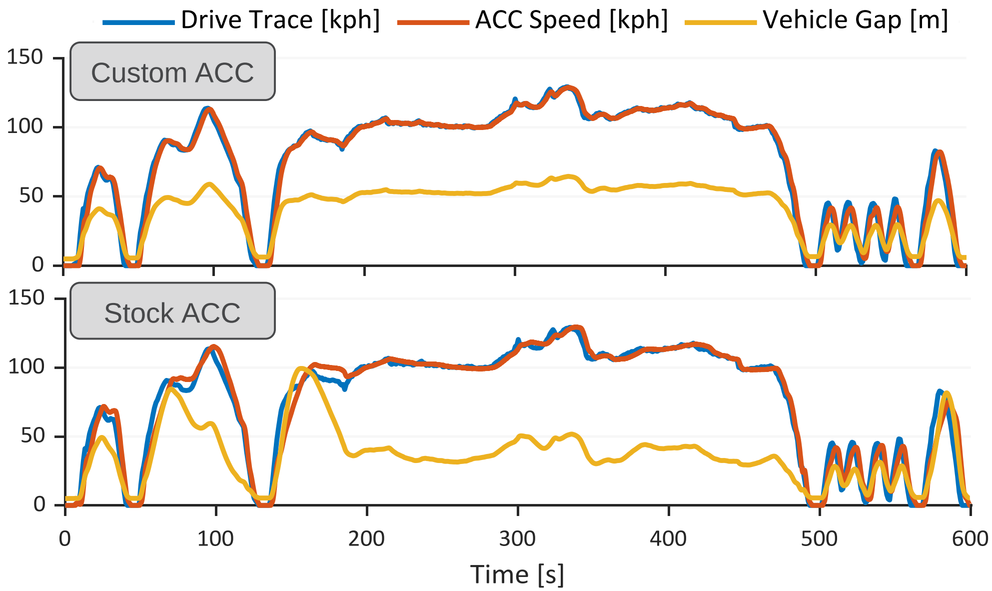
Acceleration Override



<u>ACCOMPLISHMENTS:</u> VIL IMPLEMENTATION-ENERGY USE OF LONGITUDINAL CONTROL MODELS

Following Behavior

- Stock ACC falls far behind during acceleration but catches up and maintains relatively constant time gap of ~1.1 sec
- Prototype ACC maintains a constant time gap throughout the entire drive cycle.



Fuel / Energy Consumption

- Fuel and energy consumption is unaffected on mild cycles
- Highest fuel economy impact is on the aggressive US06 cycle with charge sustaining operation
- Benefit does not appear with EV operation

HEV [mpg]	UDDS	HWY	US06
Drive Trace	87.1	73.7	49.0
Prototype ACC	87.4	73.5	51.8
Stock ACC	86.8	73.0	50.9

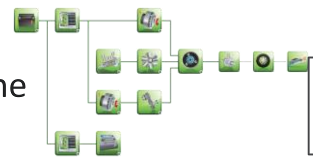
EV [Wh/mi]	UDDS	HWY	US06
Drive Trace	132.7	159.6	234.7
Prototype ACC	135.1	160.4	230.4
Stock ACC	134.7	160.2	237.7

*SOC corrected fuel economy from direct fuel scale

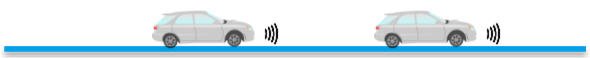
ACCOMPLISHMENTS:
VIL – ROADRUNNER VALIDATION

1 – Define Same Scenario & Select Powertrain

Route: HWFET, UDDS
Vehicles: PHEV. Toyota Prius Prime



Scenario: 2-passengers platoon with automatic longitudinal control

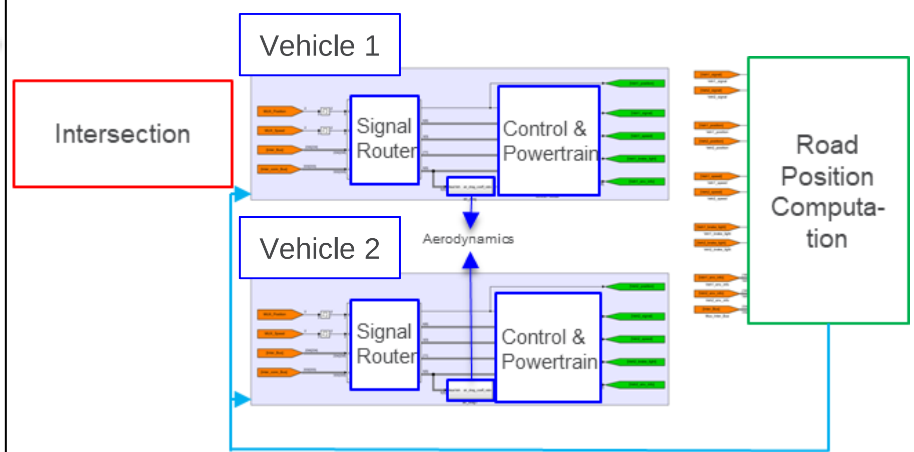


- **The lead vehicle is following a speed trace same as standard cycles.**
- **The two followings vehicles control their speed with IDM or CACC.**
- The ACC operates at the same vehicle location as the test data.

Automated Model Building

2. Scenario Simulation

Closed-Loop CAV Simulation Framework

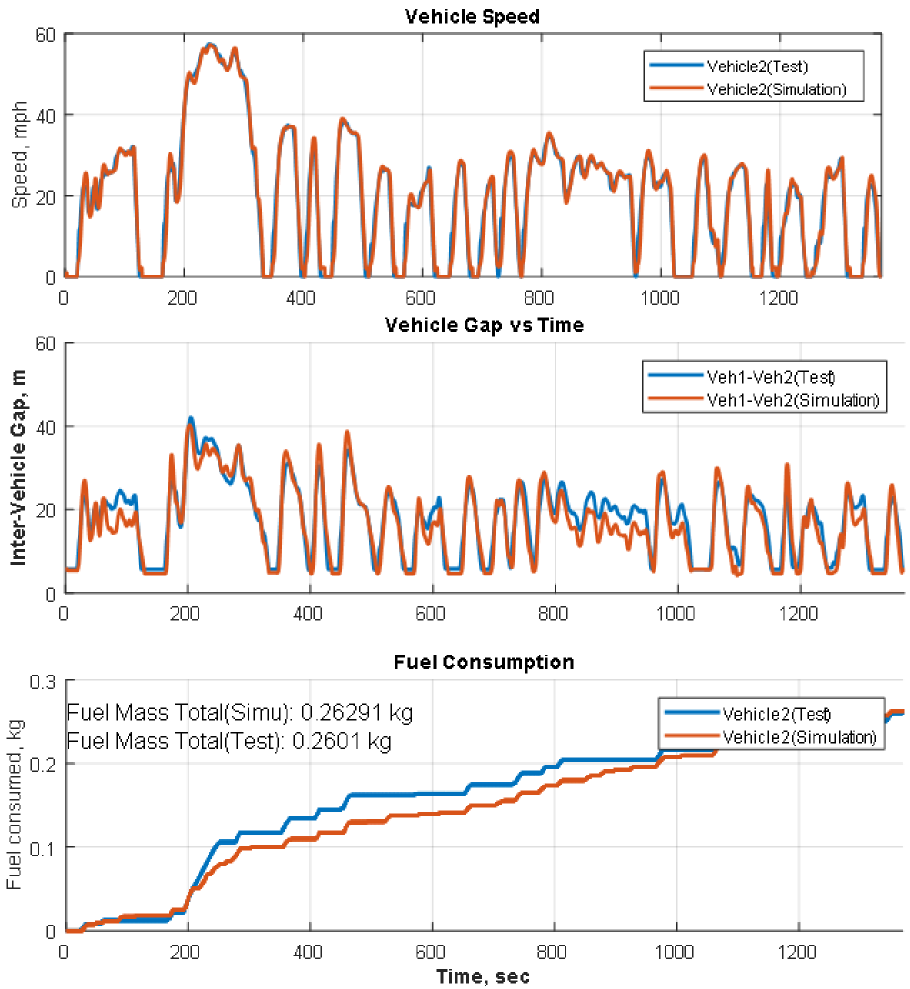


The simulation diagram includes: each vehicle powertrain, a driving controller, route specs (grade, etc.), and the information exchange links between these components.

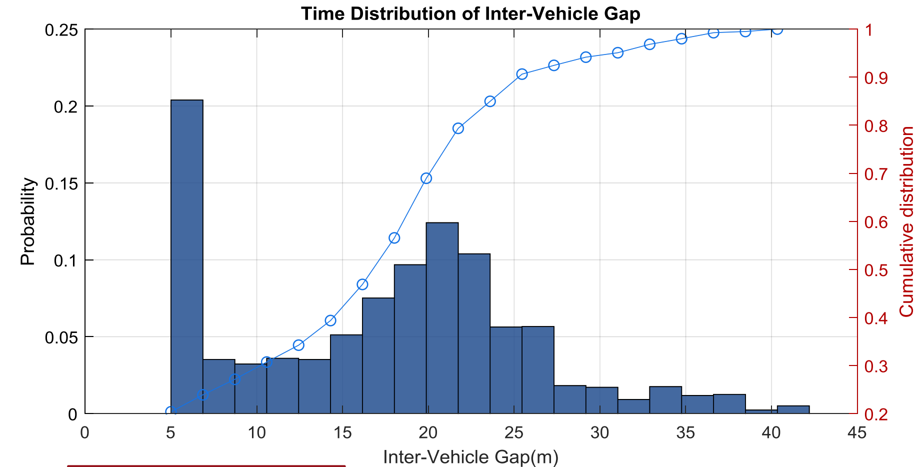
3. Compare Simulation Results with Test Data

scenario**: 2-Prius Prime platooning**

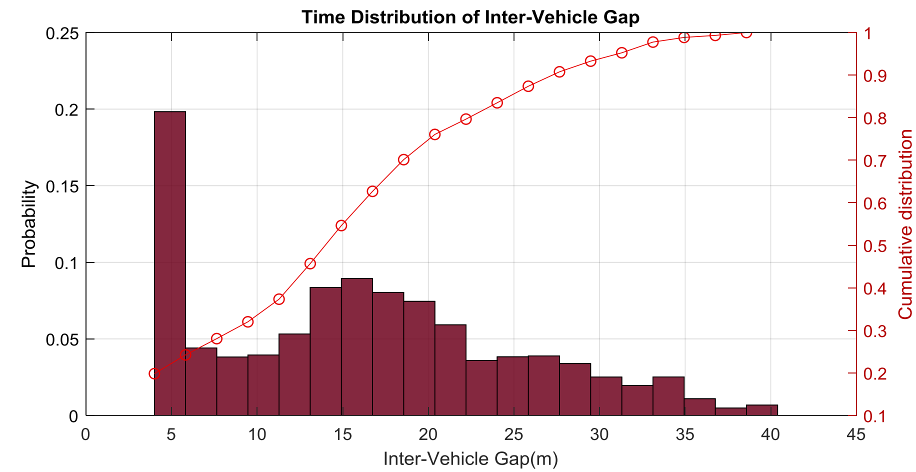
ACCOMPLISHMENTS:
VIL – ROADRUNNER VALIDATION



Test (veh2)



Simulation (veh2)



RESPONSES TO REVIEWER COMMENTS FROM PAST YEAR

- **The ANL – Core Tools Hardware project is a new start**

COORDINATION: EXISTING COLLABORATIONS WITH OTHER INSTITUTIONS

DOE National Laboratory Partners:

- ANL Modeling and Simulation
- DOE SMART Mobility Pillars where/when applicable
- ANL Cybersecurity Research

Outside Partners / Collaborators:

- US DOT- NHTSA
  - Vehicle and equipment support
- Innovative Vehicle Institute (IVI)
- Universities (Data / instrumentation support)
  - Clemson University
  - Michigan Tech
- Publicly available vehicle data
  - www.anl.gov/d3

REMAINING CHALLENGES AND BARRIERS

- **Vehicle-in-the-Loop (VIL)**
  - **Integration of VIL in real-time simulation environment**
    - Implementation challenge of emulated environment on hardware
    - Latency limitations in real-time environment processing
    - Systems integration for added V2X hardware can be quirky
  - **Vehicle control override implementation**
    - Vehicle communication is non-public, requiring extensive expertise in reverse engineering for control of additional vehicles.
    - Communication varies from models, and extensively between makes
    - Enabling proper “state” for continuous vehicle control during VIL testing
- **Aero**
  - Automation of vehicle longitudinal control for platooning
  - Dynamic gap approach unsuccessful in short sections, requiring refinement / new track
  - Test time efficiency improvements (where possible)

PROPOSED FUTURE WORK

Vehicle in the Loop

- Control and evaluate energy-centric CAV behavior within an emulated environment (closed loop!)
  - Infrastructure communication emulation (V2X, etc)
  - Roadway emulation
  - Driver in the Loop ?
- Expansion of research vehicle fleet
  - Variation in available manufacturer and powertrain architectures
  - Expansion of vehicle control overrides (SOC, gear,…)
- Data distribution for public use through www.anl.gov/d3

Aero

- Continued testing with additional vehicle profiles
- Additional testing with varying (longer) gaps and improved instrumentation
- Evaluation of multi-vehicle platoons

Note- Any proposed future work is subject to change based on funding levels

SUMMARY

Relevance

- Innovative methods of both modeling and testing are required to accurately quantify the impact of future automotive technologies on Mobility, Energy, and Productivity.

Approach

- Development of a vehicle-centric testing environment for model validation and direct research into Connected and Automated Vehicle (CAV) technologies.
- Quantification of road-load impact of vehicle platooning through direct measurement.

Highlighted Accomplishments

- Vehicle-in-the-Loop development and demonstration with energy-centric evaluation of HEV and EV behavior.
- Vehicle-in-the-Loop validation of RoadRunner
- Successful initial quantification of road load reduction in a two vehicle platoon.

TECHNICAL BACK-UP SLIDES

Advance Mobility Technology Laboratory
4WD Chassis Dynamometer Thermal Test Cell

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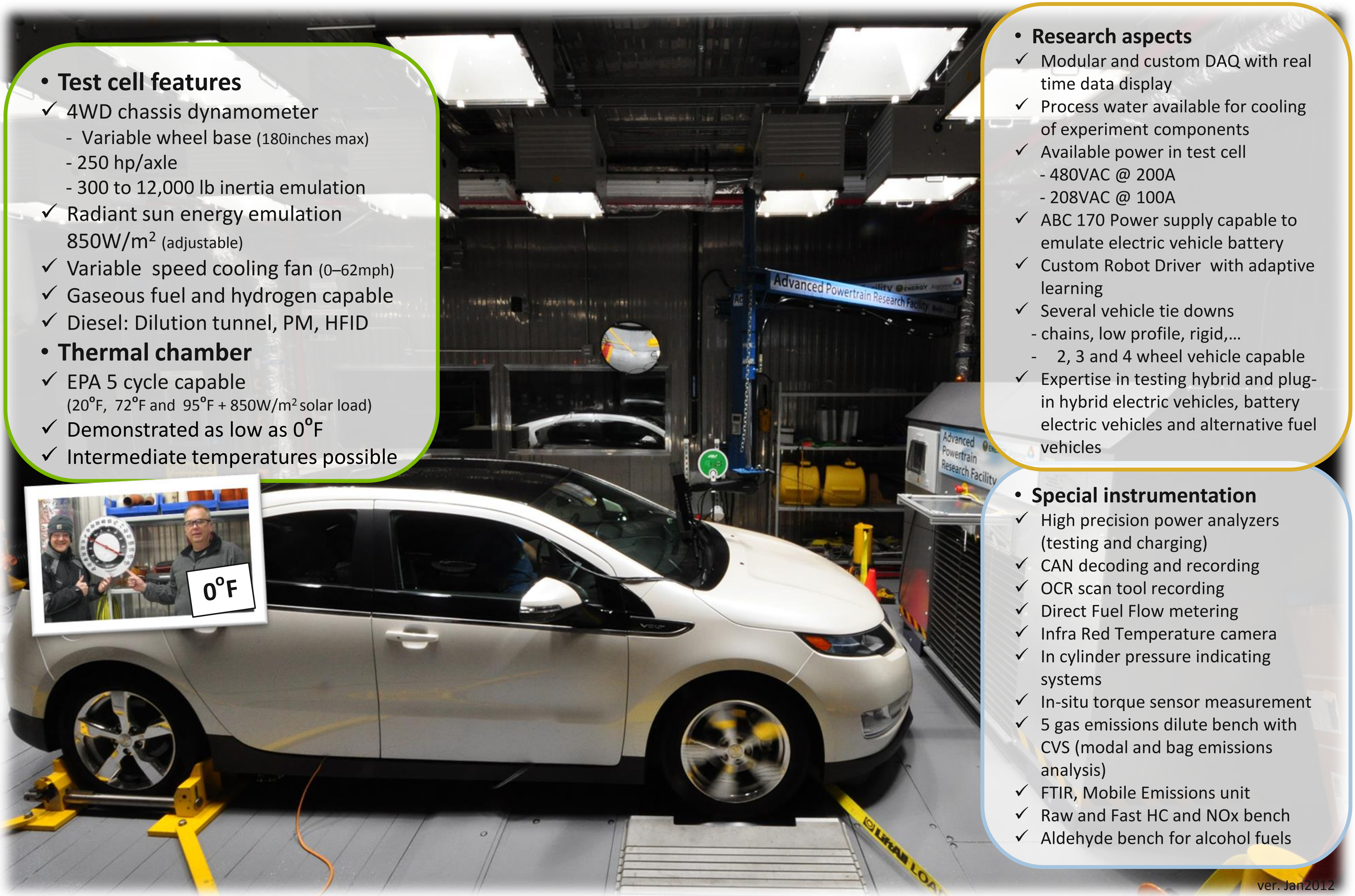

- **Test cell features**
  - ✓ 4WD chassis dynamometer
    - Variable wheel base (180inches max)
    - 250 hp/axle
    - 300 to 12,000 lb inertia emulation
  - ✓ Radiant sun energy emulation 850W/m^2 (adjustable)
  - ✓ Variable speed cooling fan (0–62mph)
  - ✓ Gaseous fuel and hydrogen capable
  - ✓ Diesel: Dilution tunnel, PM, HFID
- **Thermal chamber**
  - ✓ EPA 5 cycle capable (20°F, 72°F and 95°F + 850W/m^2 solar load)
  - ✓ Demonstrated as low as 0°F
  - ✓ Intermediate temperatures possible

- **Research aspects**
  - ✓ Modular and custom DAQ with real time data display
  - ✓ Process water available for cooling of experiment components
  - ✓ Available power in test cell
    - 480VAC @ 200A
    - 208VAC @ 100A
  - ✓ ABC 170 Power supply capable to emulate electric vehicle battery
  - ✓ Custom Robot Driver with adaptive learning
  - ✓ Several vehicle tie downs
    - chains, low profile, rigid,…
    - 2, 3 and 4 wheel vehicle capable
  - ✓ Expertise in testing hybrid and plug-in hybrid electric vehicles, battery electric vehicles and alternative fuel vehicles
- **Special instrumentation**
  - ✓ High precision power analyzers (testing and charging)
  - ✓ CAN decoding and recording
  - ✓ OCR scan tool recording
  - ✓ Direct Fuel Flow metering
  - ✓ Infra Red Temperature camera
  - ✓ In cylinder pressure indicating systems
  - ✓ In-situ torque sensor measurement
  - ✓ 5 gas emissions dilute bench with CVS (modal and bag emissions analysis)
  - ✓ FTIR, Mobile Emissions unit
  - ✓ Raw and Fast HC and NOx bench
  - ✓ Aldehyde bench for alcohol fuels

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Advanced Mobility Technology Laboratory
2WD Chassis Dynamometer

- **Test cell features**
  - ✓ 2WD Light Duty / Medium Duty chassis dynamometer
    - 300 hp
    - 300 to 14,000 lb inertia emulation
    - 10,000 lb max weight driven axle
  - ✓ Multiple cooling fans available
  - ✓ Vehicle lift (max 10,000 lb)
  - ✓ Remotely located control room with conference area

- **Research aspects**
  - ✓ Modular and custom DAQ with real time data display
  - ✓ Flexible to adopt any drive cycle
  - ✓ Available power in test cell
    - 480VAC @ 200A & 100A
    - 208VAC @ 50A, 30A & 20A x3
  - ✓ ABC 170 power supply capable to emulate electric vehicle battery
  - ✓ Custom Robot Driver with adaptive learning
  - ✓ Expertise in testing hybrid and plug-in hybrid electric vehicles, battery electric vehicles and alternative fuel vehicles

- **Special instrumentation**
  - ✓ High precision power analyzers (testing and charging)
  - ✓ CAN decoding and recording
  - ✓ OCR scan tool recording
  - ✓ Direct Fuel Flow metering
  - ✓ Infra Red Temperature camera
  - ✓ In cylinder pressure indicating systems
  - ✓ In-situ torque sensor measurement
  - ✓ SEMTECH-DS (Mobile Emissions unit) with AVL DVE mass flow sensor

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